

ACI 374.3R-16

Guide to Nonlinear Modeling Parameters for Earthquake-Resistant Structures

Reported by ACI Committee 374



American Concrete Institute
Always advancing



Guide to Nonlinear Modeling Parameters for Earthquake-Resistant Structures

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at <http://concrete.org/Publications/DocumentErrata.aspx>. Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

Guide to Nonlinear Modeling Parameters for Earthquake-Resistant Structures

Reported by ACI Committee 374

Jeffrey J. Dragovich, Chair

Insung Kim*, Secretary

Mark A. Aschheim
John F. Bonacci
Joseph M. Bracci
Sergio F. Brena
Paul J. Brien
Ned M. Cleland
Juan Francisco Correal Daza
Joe Ferzli
David C. Fields

Luis E. Garcia
Garrett R. Hagen*
Wael Mohammed Hassan
Mary Beth D. Hueste
Luis F. Ibarra
Brian E. Kehoe
James M. LaFave
Andres Lepage
Adolfo B. Matamoros

Stavroula J. Pantazopoulou
Chris P. Pantelides
Jose A. Pincheira
Jeffrey Rautenberg
Jose I. Restrepo
Mario E. Rodriguez
Murat Saatcioglu
Felipe Saavedra
Guillermo Santana

Mehrdad Sasani
Shamim A. Sheikh
Myoungsu Shin
Hitoshi Shiohara
Roberto Stark
John H. Tessem
John W. Wallace
Tom C. Xia
Fernando Yanez

*Task group that developed this guide. Alvaro Celestino was also a member of the task group and primary author.

Consulting Members

Sergio M. Alcocer

Ronald Klemencic

Andrew W. Taylor

Special acknowledgements to Laura Basualdo, Anna Birely, Reza Dashtpeyma, Wassim Ghannoum, and Andrew Shuck for their contributions to this guide.

This guide provides information regarding nonlinear modeling of components in special moment frame and structural wall systems resisting earthquake loads. The reported modeling parameters provide a modeling option for licensed design professionals (LDPs) performing nonlinear analysis for performance-based seismic design of reinforced concrete building structures designed and detailed in accordance with ACI 318.

Keywords: backbone curve; beams; columns; coupling beams; earthquake-resistant structures; flexure; joints; modeling parameters; nonlinear analysis; performance-based engineering; seismic design; shear; special concrete moment frames; special concrete shear walls; special structural walls.

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE, p. 2

- 1.1—Introduction, p. 2
- 1.2—Scope, p. 2

CHAPTER 2—NOTATION AND DEFINITIONS, p. 3

- 2.1—Notation, p. 3
- 2.2—Definitions, p. 4

CHAPTER 3—GENERAL, p. 4

- 3.1—General, p. 4
- 3.2—Backbone curve selection procedure, p. 5

CHAPTER 4—NONLINEAR MODELING PARAMETERS FOR SPECIAL CONCRETE MOMENT FRAMES, p. 5

- 4.1—Modeling parameters for columns, p. 5
- 4.2—Modeling parameters for beams and beam-column joints (ASCE/SEI 41), p. 5

ACI 374.3R-16 was adopted and published September 2016.

Copyright © 2016, American Concrete Institute

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

CHAPTER 5—NONLINEAR MODELING PARAMETERS FOR SPECIAL CONCRETE STRUCTURAL WALLS AND COUPLING BEAMS, p. 7

5.1—Modeling parameters for special structural walls and coupling beams controlled by flexure, p. 7

5.2—Modeling parameters for structural walls and coupling beams controlled by shear, p. 11

CHAPTER 6—SUMMARY AND CONCLUSIONS, p. 12

CHAPTER 7—REFERENCES, p. 12

Authored documents, p. 13

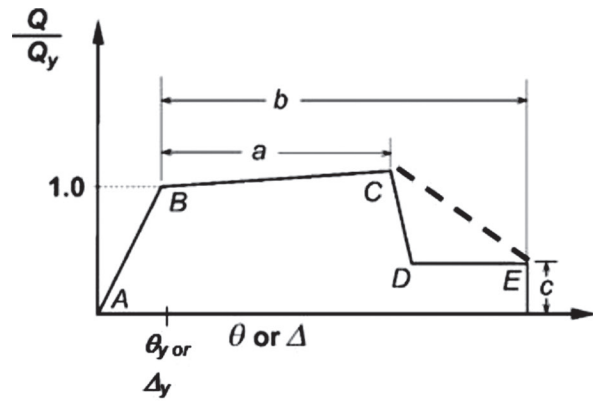
CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

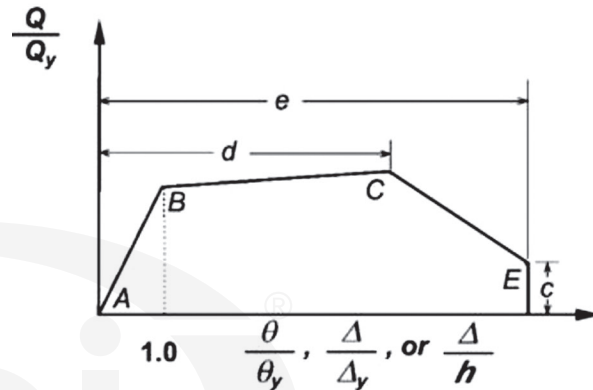
This guide provides nonlinear modeling parameters that will assist the licensed design professional (LDP) in the use of performance-based seismic design of new concrete buildings. Performance objectives are assigned for the given structure and compliance with the performance objectives are then evaluated based on the deformation of structural elements rather than evaluated based on strength under prescriptive requirements. Deformations in structural components allow the LDP to understand damage levels related to seismic hazards.

There are currently several documents that provide general analysis procedures for the design of new buildings using performance-based engineering (ASCE/SEI 7; Structural Engineers Association of Northern California [SEAONC] 2008; Los Angeles Tall Buildings Structural Design Council [LATBSDC] 2014; Pacific Earthquake Engineering Research Center [PEER] [PEER/ATC 2010]). Although these documents provide a means for seismic design indicative of earthquake hazards and acceptance criteria that are similar to ASCE/SEI 41, they do not provide the required information for modeling nonlinear behavior of a structural component based on detailing conditions, such as the development of force-deformation backbone curves shown in Fig. 1.1. This guide provides modeling parameters that can be used to generate the backbone curves of structural members of special moment frame and structural wall systems detailed per Chapter 18 of ACI 318-14.

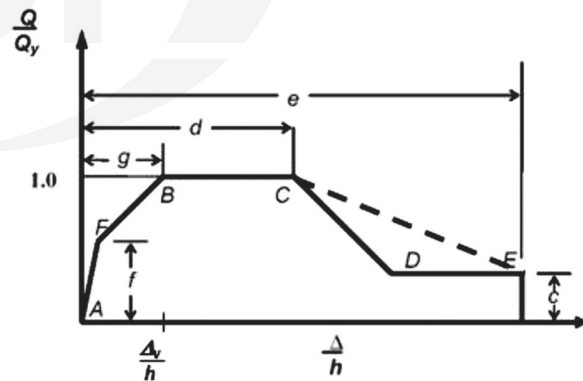
For example, an engineer modeling the nonlinear deformation of a structural wall with specific reinforcement configurations for new design can select from the following three alternatives: 1) develop modeling parameters from existing experimental data; 2) develop and implement a new testing program; or 3) create force-deformation curves using the information in the existing building standard (ASCE/SEI 41) or guideline (ACI 369R) developed for seismic evaluation and rehabilitation. The existing experimental data, however, are not always available, and new testing programs may be limited by budget and project schedule. In addition, the modeling parameters in the existing building standard do not always adequately represent the behavior of components designed according to current codes. Furthermore, they may not be directly applied to new design due to incongruences



(a) Plastic deformation



(b) Deformation ratio or drift



(c) Deformation ratio or drift – Tri-linear response

Fig. 1.1—Generalized force-deformation relations for structural concrete components (ASCE/SEI 41). (Note: a, b, d, e, f, and g are deformations as defined in the reported nonlinear modeling parameter tables.)

in parameter definition and requirements across documents. This guide provides a set of nonlinear modeling parameters that can be used without performing one of the three alternatives given.

1.2—Scope

This guide provides information about nonlinear modeling parameters for:

(a) Special moment frames extracted from ASCE/SEI 41, for which definitions and requirements are converted to those of the codes for the design of new concrete buildings

(b) Special structural walls and coupling beams extracted from ASCE/SEI 41, for which definitions and requirements are converted to those of the codes for the design of new concrete buildings

(c) Special moment frames and structural walls developed from the latest experimental databases of structural components compliant with the requirements of Chapter 18 (ACI 318-14) for earthquake-resistant structures.

In regards to (c), the mean and mean minus one standard deviation modeling parameter values are provided for these code-compliant specimen databases in an effort to demonstrate a quantitative representation of data distribution for the LDP. The LDP can select modeling parameters based on ASCE/SEI 41, or the experimental database, depending on project constraints, jurisdiction requirements, or both.

The modeling parameters in this guide are meant to be used for the analytical modeling of structural components in earthquake-resistant systems as described. The guide, however, does not describe global behavior or provide interaction between different systems in the buildings, for example, diaphragms and moment frames.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_{cv} = gross area of concrete section bound by web thickness and length of section in the direction of shear force considered, in. ² (mm ²)	h_c = average height of the beams framing into the joint in the direction of applied shear, in. (mm)
A_g = gross area of concrete section, in. ² (mm ²)	h_{eff} = effective shear span of wall, in. (mm)
A_j = effective cross-sectional area within a joint in a plane parallel to plane of beam reinforcement generating shear in the joint, in. ² (mm ²) (ACI 318-14 Section 18.8.4.3)	h_w = height of entire wall from base to top, or clear height of wall segment or wall pier, in. (mm)
A_s = area of nonprestressed longitudinal tension reinforcement, in. ² (mm ²)	I_{cr} = moment of inertia of cracked section transformed to concrete, in. ⁴ (mm ⁴)
A_s' = area of compression reinforcement, in. ² (mm ²)	I_g = moment of inertia of gross concrete section about centroidal axis, neglecting reinforcement, in. ⁴ (mm ⁴)
A_v = area of shear reinforcement within spacing s , in. ² (mm ²)	L = length of member along which deformations are assumed to occur, in. (mm)
b = width of compression face of member, in. (mm)	ℓ_d = development length in tension of deformed bar, deformed wire, or plain wire reinforcement, in. (mm)
b_w = web width, or diameters of circular section, in. (mm)	l_p = assumed plastic hinge length, minimum of the following: $0.5l_w$, the first-story height, and $0.5h_w$ for wall segments, in. (mm)
d = distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in. (mm)	l_w = length of entire wall, or length of wall segment or wall pier considered in direction of shear force, in. (mm)
E = effect of horizontal and vertical earthquake-induced forces	M_n = nominal flexural strength at section, in.-lb (N-mm)
E_c = modulus of elasticity of concrete, psi (MPa)	M_{pr} = probable flexural strength of members, with or without axial load, determined using the properties of the member at the joint faces assuming a tensile stress in the longitudinal bars of at least $1.25f_y$ and a strength reduction factor ϕ of 1.0, in.-lb (N-mm)
E_s = modulus of elasticity of reinforcement and structural steel, psi (MPa)	P = design axial force obtained from design load combinations that include overstrength factor or determined from limit-state analysis, lb (N)
f_c' = specified compressive strength of concrete, psi (MPa, $\sqrt{f_c'}$ in MPa = $12\sqrt{f_c'}$ in psi)	Q = generalized force demand in a component
f_y = specified yield strength of reinforcement, psi (MPa)	Q_y = yield strength of a component
h = height of member along which deformations are measured, in. (mm)	s = center-to-center spacing of transverse reinforcement, in. (mm)
h_b = subgrade dimension from absolute base of wall to grade level, in. (mm)	V = design shear force obtained from design load combinations that include overstrength factor or determined from limit-state analysis, lb (N)
	V_e = design shear force for load combinations including earthquake effects, lb (N) (refer to ACI 318-14 Sections 18.6.5.1 and 18.7.6.1.1)
	V_n = nominal shear strength, lb (N)
	V_o = shear strength of a column per ASCE/SEI 41 Eq. (10-3), lb (N)
	V_p = shear demand on a column at flexural yielding of plastic hinges per ASCE/SEI 41 Section 10.4.2.2.2, lb (N)
	V_{si} = nominal shear strength provided by shear reinforcement, lb (N)
	Δ = generalized deformation, in. (mm)
	Δ_y = generalized yield deformation, in. (mm)
	ϵ_y = yield strain of reinforcement, in./in. (mm/mm)
	θ = generalized deformation, radians
	θ_y = generalized yield deformation, radians
	ϕ = strength reduction factor
	ϕ_y = yield curvature at section, 1/in. (1/mm)
	ρ = ratio of nonprestressed tension reinforcement
	ρ' = ratio of nonprestressed compression reinforcement
	ρ_b = ratio of A_s to bd producing balanced strain condition
	ρ_v = ratio of A_v to $b_w s$